Georgia Tech Sponsored Research

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Project	E-20-E66 H2652		
Project director	HAJ-ALI	RAMI	13
Research unit	Civil Eng		
Title	CAREER:NESTED 3-D MICROMECHANICAL & DAMAGE MODELS FOR ANALYSIS FOR ~~OF~~ Pultruded and laminated Composite Structures		
Project date	6/30/2004		

E-20-E66
#4

Final Report for Period: 04/1999 - 03/2004
Submitted on: 05/25/2004
Principal Investigator: Haj-Ali, Rami M.
Award ID: 9876080
Organization: GA Tech Res Corp - GIT
Title:
CAREER: Nested 3-D Micromechanical and Damage Models for Analysis of Pultruded and Laminated Composite Structures

Project Participants

Senior Personnel

Name: Haj-Ali, Rami
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Graduate Student

Name: Dokun, Olajide
Worked for more than 160 Hours: Yes
Contribution to Project:
Olajide D. Dokun (David) is my PhD. student he was supported through this award

Name: Kilic, Hakan
Worked for more than 160 Hours: Yes
Contribution to Project:
Hakan Kilic is my PhD. student he was supported through this a ward.

Name: Hanifah-Muliana, Anastasia
Worked for more than 160 Hours: Yes
Contribution to Project:
Anastasia (Ana) Started working with me on her PhD and she is partially supported by this NSF award

Name: El-Hajjar, Rani
Worked for more than 160 Hours: Yes
Contribution to Project:
Rani is a PhD graduate students that joined my reasearch group a year ago. He is currently supported by this grant.

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Other Collaborators or Contacts

Collaboration was conducted with Drs. Laurence Jacobs, Abdul-Hamid Zureick, Donald White, Kim Kurtis at CEE, Georgia Tech.

Interdepartmental and interdisciplinary collaborations at Georgia Tech with Drs. Ashok Saxena, Erian Armanious, and George Kardomateas.

Other major collaboration between myself and Drs. Robert Dodds, Jr., David Pecknold, and Jamshid Ghaboussi at the University of Illinois at Urbana Champaign, George Voyiadjis at LSU and Valeria La Saponara at University of Utah.

Industry collaboration was also ongoing with Dr. Steve Englestand, a Technical Fellow at Lockheed Martin Marietta, GA.

Activities and Findings

Research and Education Activities:

The major activities of this project can be summarized as:

1) Applying and expanding a class of new 3D nonlinear micromechanical models for the analysis of thick-section thin laminated composites materials and structures with and without damage effects.

2) Extensive experimental program was conducted to validate the nonlinear modeling behavior of laminated composites and thick-section multi-layered composites. Because of this effort, modifications to current ASTM mechanical standards were needed and new testing procedures for pultruded composites were investigated and applied.

3) New combined experimental analytical program to characterize damage, fracture toughness, and crack growth was conducted.

4) Finite element nonlinear and multi-scale material models were formulated for the nonlinear and time-dependent analysis of fiber reinforced polymeric (FRP) composites.

5) Testing program for short-term viscoelastic behavior of E-Glass/Vinylester composites was performed and used to calibrate the in-situ behavior of the polymeric matrix both with variable stress levels and with time-dependent response.

7) A new nonlinear multi-scale viscoelastic framework for FRP composites that can effectively couple micromechanical models while performing global analysis is formulated with special attention to applying new stress-update algorithms at all levels of the framework.

8) New experimental fracture toughness and crack propagation testing was conducted in thick FRP composites.

9) A coupled cohesive crack growth FE models with multi-scale constitutive models are used to predict the crack growth in thick-section composites.

10) Structural models for bolted connections, lap joints, cylindrical shells, long composite columns, among others, were all modeled with the new multi-scale composite models.

11) A new infrared (IR) thermal stress analysis setup was built and applied to measure damage in metallic and composites materials.

Some of the highlights of the education activities of this project included:

1) Initiate new curriculum development as part of the advanced composite mechanics and structural analysis courses that is offered yearly at Georgia-Tech. I have been teaching a cross-listed inter-disciplinary course for the last 7 years and it is shared by several schools: AE, ME, CEE, and MSE.

2) Active involvement with the Composites Education and Research Center (CERC) at Georgia Tech during the project which included undergraduate and graduate curriculum development and offers a professional certificate in composites for both undergraduate and graduate students.

3) This project allowed offering a research experience for several undergraduate students. Undergraduate students joined my research group

and helped in the ongoing research especially in the lap.

4) Build a computational cluster composed of several Unix-based workstations connected with personal computers for parallel and serial computer simulation of matrial and structural behavior.

5) Encouraging students from underrepresented groups was on of the most rewarding experience during this project. I am please to say that two formal students, Dr. David Dokun, an African-American, and Dr. Anastasia Muliana, an Asian-female, have been directly supported from this NSF award. They both encouraged other students to follow their footsteps. Dr. Muliana has recently accepted a faculty position at Texas A&M.

Findings:

Major finding include:

1) Experimental results were successfully conducted to verify and confirm the ability of the proposed 3D multi-scale material models to predict the nonlinear, time-dependent, and damage response of thick and thin multi-layered FRP composites.

2) New numerical constitutive models were first introduced for viscoelastic behavior, nonlinear and damaged response and crack growth.

3) Nonlinear Artificial Neural Network (ANN) were first introduced and used to simulate the microstructral responses.

4) The proposed micromechanical-modeling framework can be effectively integrated in a finite element codes for nonlinear analysis and simulation of structural components with relatively small computational premium.

5) Testing program for short-term viscoelastic behavior of E-Glass/Vinylester composites was successful. The proposed constitutive models have successfully extended to nonlinear viscoelastic models for the matrix phase. Calibration and prediction of the modeling approach are in good agreement with the tested results. Theoretical and effective numerical algorithms were developed and implementations for nonlinear viscoelasticity and can be used also for modeling the anisotropic and classical isotropic viscoelastic behavior of polymers.

6) Cohesive models were generated for fracture in Mode-I and Mode-II (trans-layer modes) in thick-section layered composites. These have shown good prediction compared to the experimental data.

7) Testing procedure for fracture toughness was examined.

8) A new quantitative infrared (IR) thermal stress analysis (TSA) method was developed and examined on multi-layered orthotropic medium. Infrared measurements were used to extract the sum of the direct strains on the composite surface and correlate it with FE models.

Training and Development:

The project has directly helped train and graduate:

1) Dr Olajide Dokun (Co-Advised with Dr. Larry Jacobs).
2) Dr. Hakan Kilic
3) Dr. Anastasia Muliana
4) Dr. Rani El-Hajjar

These students, with others, formed a superb research group that still affects other graduate students here at Tech. Other students that benefited from the research, equipment and testing activity and were part of the group during the project:

1) Ahmet Citipitioglu, PhD student
2) Doug Miller, MS student
3) Ji-Yon Kim, MS student

Undergraduate students were always a part of my research group. They benefited from the research, equipment and testing, and the general activity during the project:

1) Kevin Stewart
2) Akshay Sthapit
3) Shane Johnson

Other training development included:

1) Organizing three symposia as part of ASCE-EM conferences and joint ASCE/ASME conference directly related to the ongoing research.

2) Organizing two different workshops at Georgia Tech related to the research project

3) Shared research finding with industrial collaborators from Lockheed Martin in Marietta Georgia.

4) Advising ASCE students on building with composite materials

Outreach Activities:

I was/am working with a Composite Education and Research Center (CERC) at Georgia-Tech. A major goal of this center is to increase the students' understanding of composite materials in engineering. The activity is not limited to research and emphasis is placed on curriculum development in composite materials as well. Certificate programs are offered for both undergraduate and graduate students in the area of composites.

Journal Publications

Olajide, D. D., Laurence, J. J., and Haj-Ali, R. M., "Ultrasonic Monitoring of Material Degradation in FRP Composites", ASCE Journal of Engineering Mechanics, p. 704, vol. 126, (2000). Published

Ghaboussi, J., Pecknold, D. A., Zhang, M-F, and Haj-Ali, R. M., "Autoprogressive Training of Neural Network Constitutive Models", Int. Journal Numerical Methods Engineering, p. 105, vol. 42, (1998). Published

Haj-Ali, R.M., Kurtis, K.E., and Sthapit, A. R., "Neural Network Modeling of Concrete Expansion During Long-Term Sulfate Exposure", ACI Materials Journal, p. 01, vol. 98, (2001). Published

Haj-Ali, R. M., Kilic, M., and Zureick, A-H, "A Three-Dimensional Micromechanics-Based Constitutive Framework for Analysis of Pultruded Composite Structures", ASCE J. Eng. Mechanics, p. 653, vol. 127, (01). Published

Haj-Ali, R. M., Pecknold, D. A., Ghaboussi, J., and Voyiadjis, G., Z., "Simulated Micromechanical Models using Artificial Neural Networks", ASCE J. Eng. Mechanics, p. 730, vol. 127, (7). Published

La Saponara, V., Muliana, H., Haj-Ali, R. M., and Kardomateas, G., A., "Experimental and Numerical Analysis of Delamination Growth in Double Cantilever laminated Beams", Engineering Fracture Mechanics, p. 687, vol. 69, (2002). Published

Citipitioglu, A. M., Haj-Ali, R. H., and White, D. W, "Refined 3D Finite Element Modeling of Partially-Restrained Connections Including Slip", Journal of Constructional Steel Research (JCSR), p. 995, vol. 58, (2002). Published

Haj-Ali, R. M., and Kilic, M., "Nonlinear Behavior of Pultruded FRP Composites", Composites Part B: Engineering, p. 173, vol. 33, (2002). Published

Muliana, A. H., Steward, R., Haj-Ali, R. H., and Saxena, A., "Artificial Neural Network and Finite Element Modeling of Nano-Indentation Tests", Metallurgical and Materials Transactions - A, p. 1939, vol. 33A, (2002). Published

Haj-Ali, R. M., and Kilic, M., "Nonlinear Constitutive Models for Pultruded FRP Composites", Mechanics of Materials, p. 791, vol. 35, (2003). Published

Haj-Ali, R. M., and El-Hajjar, R. F., "Crack Propagation Analysis of Mode-I Fracture in Pultruded Composites using Micromechanical Constitutive Models", Mechanics of Materials, p. 885, vol. 35, (2003). Published

Kilic, M., and Haj-Ali, R. M., "Progressive Damage and Nonlinear Analysis of Pultruded Composite Structures", Composites Part B: Engineering, p. 235, vol. 34, (2003). Published

Kilic, M., and Haj-Ali, R. M., "Elastic-Degrading Analysis for Pultruded Composite Structures", Composite Structures, p. 43, vol. 60, (2003). Published

Haj-Ali, R. M., and Muliana, A. H., "Micromechanical Models for the Nonlinear Viscoelastic Behavior of Pultruded Composite Materials", International Journal of Solids and Structures, p. 1037, vol. 40, (2003). Published

El-Hajjar, R.F., and Haj-Ali, R. M., "A Quantitative Thermoelastic Stress Analysis Method for Pultruded Composites", Composite Science and Technology, p. 967, vol. 63, (2003). Published

Haj-Ali, R. M., and Muliana, A. H., "Numerical Finite Element Formulation of the Schapery Nonlinear Viscoelastic Material Model", International Journal for Numerical Methods in Engineering, p. 25, vol. 59, (2004). Published

Muliana, A.H., and Haj-Ali, R.M., "Nested nonlinear viscoelastic and micromechanical models for the analysis of pultruded composite materials and structures", Mechanics of Materials, p. , vol. , ( ). Accepted

Haj-Ali, R.M., and Muliana, A.H., "A multi-scale constitutive formulation for the nonlinear viscoelastic analysis of laminated composite materials and structures", International Journal of Solids and Structures, p. 3461, vol. 41, (2004). Published

El-Hajjar, R.F., and Haj-Ali, R.M., "Mode-I Fracture Toughness Testing of Thick Section FRP Composites using the ESE(T) Specimen", Engineering Fracture Mechanics, p. , vol. , ( ). Accepted

El-Hajjar, R.F., and Haj-Ali, R.M., "In-plane shear testing of thick-section pultruded FRP composites using a modified Arcan fixture", Composites Part B: Engineering, p. 421, vol. 35, (2004). Published

Books or Other One-time Publications

Olajide D. Dokun, "Laser Ultrasonic Technique and Numerical Models for Damage and Degradation Tracking in FRP Composites", (1999). Thesis, Published
Editor(s): A PhD. Thesis report, Georgia Institute of Technology, 1999
Bibliography: PhD. Thesis, Georgia Inst. of Technology Atlanta, GA,1999.

Mustafa Hakan Kilic, "Three-Dimensional Micromechanical Models for the Nonlinear Analysis of Pultruded Composite Structures", (2002). Thesis, Accepted
Bibliography: PhD. Thesis, Georgia Inst. of Technology Atlanta, GA,2002.

Web/Internet Site

URL(s):

Description:

Other Specific Products

Contributions

Contributions within Discipline:
Major finding include:

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Contributions to Other Disciplines:

New Artificial Neural Networks (ANN) material models were proposed for simulation of material response by training from numerical micromechanical models.

Contributions to Human Resource Development:

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Contributions to Resources for Research and Education:

New equipment have been purchased to enhance the current capabilities for both the computational and experimental aspects.

A new lab has been established using this NSF and other funding that will help validate the proposed micromechanical and structural models (modeling) approaches.

Contributions Beyond Science and Engineering:

Industry collaboration was conducted during the NSF research project. New and modified testing methods have been found. One outcome of this research is a proposal to ASTM to modify the ASTM-1922 toughness standard to be more applicable to thick-section composites manufactured by the pultrusion process

Categories for which nothing is reported:

Organizational Partners

Any Product